BULLETIN No. 15. S. 23.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF SOILS.

ELECTRICAL INSTRUMENTS

FOR

DETERMINING THE MOISTURE, TEMPERATURE, AND SOLUBLE SALT CONTENT OF SOILS.

BY

LYMAN J. BRIGGS,
ASSISTANT CHIEF, DIVISION OF SOILS.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Division of Soils,
Washington, D. C., March 30, 1899.

Sir: I have the honor to transmit herewith a report upon electrical instruments for determining the moisture, temperature, and soluble salt content of soils, prepared by Mr. Lyman J. Briggs, assistant chief, and to recommend that it be published as Bulletin No. 15 of this division.

Respectfully,

Milton Whitney,
Chief of Division.

Hon. James Wilson,
Secretary of Agriculture.

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ELECTRICAL INSTRUMENTS FOR DETERMINING THE MOISTURE, TEMPERATURE, AND SOLUBLE SALT CONTENT OF SOILS.

INTRODUCTION.

The determination of the water content of soils in place by means of the variation in the electrical resistance was first investigated by Prof. Milton Whitney in 1887. He first attacked the problem by measuring the variation in the internal resistance of an earth battery, consisting of alternate copper and zinc plates buried in the soil. This method was found not to be satisfactory on account of the polarization of the plates. Measurements of the resistance between large copper plates buried at the desired depth were next made with a direct current, but polarization again interfered seriously. The Kohlrausch bridge method, employing alternating currents, was finally successfully used, and various forms of electrodes were tested, difficulty being experienced at that time in maintaining good contact between the electrodes and the soil.

In 1895 the method was further developed in the Division of Soils by Professor Whitney and Dr. F. A. Wolff. The resistance-temperature coefficient of the soil, which in the preliminary work had not been considered, was determined in order that the measurements might be corrected for temperature. An instrument for field measurements was designed, which could also be used for determining the temperature of the soil by measuring the resistance of a small hermetically sealed cell containing an electrolyte, the temperature coefficient of which was known.

In 1896 the writer eliminated the effect of temperature on the measurements by balancing the soil resistance against an electrolyte having the same temperature coefficient as the soil, placed in a sealed cell near the electrodes, so as to acquire the same temperature. The method of moisture determination as thus developed, together with methods of determining the temperature and soluble salt content, were published in 1897 in bulletins Nos. 6, 7, 8, and 12 of the Division of Soils.

It is the object of this bulletin to describe the instruments and methods at present employed by this division in investigating the moisture and temperature of soils in the field, together with a convenient field apparatus for investigating the soluble salt content of soils. Several

important modifications in the instruments and methods, as previously described in other bulletins of the division, have been made. A special instrument is now used for each of the three classes of determinations, instead of a single instrument as heretofore. This change greatly simplifies the instruments, makes them easier to operate, materially lessens their cost, and, in the case of the moisture and temperature instruments, permits the use of direct reading scales, thus avoiding, except in cases where more than ordinary accuracy is desired, the necessity of any reduction of the results obtained.

The necessary information regarding the water content of the soil can of course be obtained by the ordinary method of sampling and determining the loss in weight through drying, and when carefully done probably no more accurate method exists. It was for the purpose of avoiding the laborious sampling, weighing, and drying, with certain errors commonly incident thereto, and for the advantage of being able to make determinations frequently and quickly in the field, that the electrical method of moisture determination was devised. While equally valuable experimentally, this method is also capable of certain economic applications.

It is believed that an important use of the moisture apparatus is to be found in connection with irrigation operations, in determining when there is sufficient water present in the soil and when it becomes necessary to add more water. It is obvious that a knowledge of the water content of the soil at any desired distance below the surface, even though it be only approximate, must prove to be of great service in the intelligent application of water. With a knowledge of the water content of the soil at various depths, and an understanding of the peculiarities of the crop grown, water can generally be supplied only as needed and all excess of water, resulting in seepage with the attendant translocation of salts which has proved to be so injurious, can probably be largely avoided. This excess of water can thus be saved to be applied in a useful way, and the deeper rooting of the plants, resulting from the more judicious application of water, will render them less sensible to conditions approaching drought.

The moisture instrument is also generally well adapted to indicate the water content of the beds of commercial greenhouses and has been used successfully in this connection in some large violet houses in the suburbs of Washington. Since the water content of the soil, however, is only one of the several factors which must be considered in successful greenhouse management, the indications of the instrument as applying to the treatment of the plant must always be considered in connection with the temperature, humidity, and amount of sunshine. When used in this manner it is believed that the apparatus may prove to be of much service in the commercial greenhouse.

Used as above mentioned little more is required of the moisture apparatus than to indicate when certain limits representing drought and excess of water, respectively, have been reached, and to show at

any time the state of the water content with reference to these limits. In other words, it is a knowledge of the departure of the water content from the optimum condition rather than the absolute percentage of water that is desired. In order, however, that the percentage of water may be obtained when desired, the instrument is provided with a special scale from which the approximate water content, expressed in percentage of the dry weight of the soil, may be determined directly, after a single standardization to give the relation between the readings of the instrument and the actual water content has been made by drying samples of the soil. Since the relation between the electrical resistance and the water content is not strictly the same for all soils, in case especially accurate moisture determinations are required, as in the comparison of cultural methods, it is advisable to make careful moisture determinations from time to time by sampling and drying, in order to determine the corrections, if any, to be applied to the instrument readings at different parts of the scale for the particular soil under investigation.

ELECTRICAL METHOD OF MOISTURE DETERMINATION.

The electrical method of moisture determination is based upon the principle that the resistance offered to the passage of an electrical current from one electrode to another buried in the soil, varies with the amount of water present in the soil. In nearly all soils throughout the range of water content favorable to plant development, it has been found by Whitney and Gardner [1] that the electrical resistance is very nearly inversely proportional to the square of the water content expressed in percentage of the dry weight of the soil.

The soluble salts of the soil form with the moisture a salt solution, and it is the amount, concentration, and temperature of this salt solution that determines the resistance of the soil. In order to employ the electrical resistance as a means of measuring the water content, it is necessary to maintain the temperature and the amount of salt in solution constant, or to correct for their variation. Changes in resistance due to temperature are corrected by balancing the resistance between the soil electrodes against the resistance of an electrolytic cell, which is buried near the soil electrodes and which is filled with a salt solution having the same temperature coefficient as the soil itself. As regards the quantity of soluble salts present, it can be said that no gradual variation in the resistance due to a change in the salt content seems to take place during a season. In a few instances a sudden change in the position of the moisture curve, following very heavy rains, indicated that a movement of the soil or a leaching of salts had taken place. Such a change, however, will at once be apparent and can be easily corrected by restandardizing the instrument.

The electrodes are buried in the soil at the desired depth at the

[1] Bulletin No. 12, Division of Soils, p. 15.

beginning of the growing season and remain undisturbed during the development of the plant. From these electrodes insulated wires lead to the measuring instrument, which may be located at any convenient place. By this method of moisture determination one is enabled to investigate the changes in water content in the same portion of soil throughout the season, instead of dealing with different samples, as is necessitated in the tube method of sampling and drying. The advantage of always working with the same portion of soil is emphasized by the fact that a difference in water content of 2 or 3 per cent in duplicate samples is not an uncommon experience with those who have used the tube method.

SOIL HYGROMETER.

The moisture instrument, by means of which the resistance between the soil electrodes is measured and to which the name "soil hygrometer" has been applied, is an adaptation of the well known Wheatstone bridge method of measuring electrical resistances. The instrument,

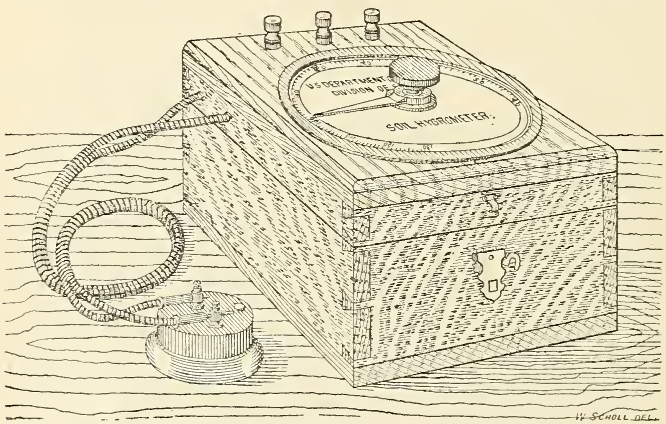

FIG. 1.—Soil hygrometer closed, ready for use, showing binding posts, scale, and central plunger operating battery switch.

which is illustrated in figs. 1 and 2, consists of a slide-wire bridge, provided with an induction coil, current interrupter, battery, and telephone receiver, suitably arranged for electrolytic measurements and inclosed in a small wooden case 8 inches long, 7 inches wide, and $4\frac{3}{8}$ inches high. The inside of the case is partitioned off in such a manner as to provide a space for the battery and also to form a small box for the reception of the current interrupter and induction coil. In the top of a partition running lengthwise through the middle of the box a series of steps is cut, on which the two springs of the battery switch are fastened in such a manner as to bring the ends of the springs directly beneath a plunger in the balancing mechanism. The central partition carrying the battery switch, together with the small case inclosing the current interrupter, can be seen in fig. 2.

BRIDGE WIRE.

The bridge wire consists of a No. 24 B. and S. platinoid wire about 64 cm. long. This wire is mounted upon the periphery of a wooden disk on the inside of the cover of the box in such a manner as to permit contact with a movable slide. The wire on the disk is so adjusted that there remains free at one end a portion about 16 cm. long, and at the other end a portion about 8.5 cm. in length. These are so coiled as to prevent short circuiting and are carefully soldered at their free ends to the left and right hand binding posts, respectively, as shown in the illustration. The wooden disk which carries the bridge wire is constructed of well-seasoned cherry and thoroughly covered with shellac. The periphery of this disk is smoothly polished and has a slight groove cut

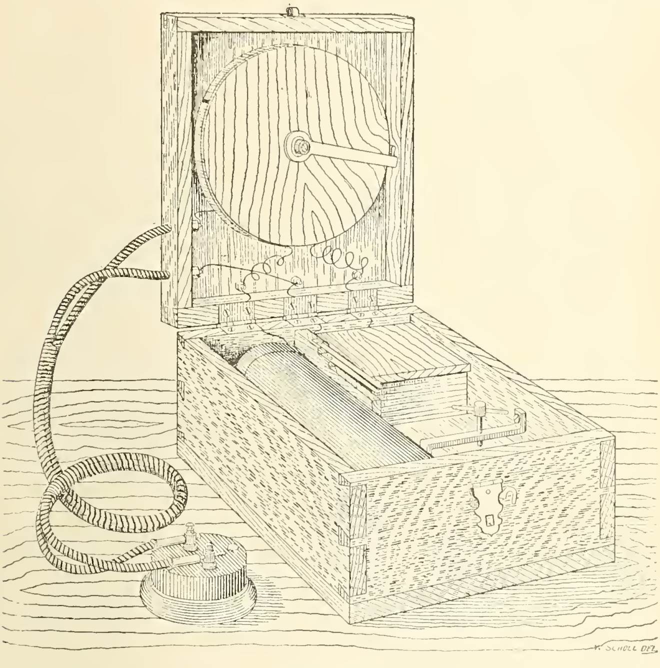

FIG. 2.—Soil hygrometer open, showing battery, screw for adjusting condenser, bridge wire, and battery switch.

in its surface one-fourth inch from the exposed face, the groove being of sufficient depth to retain the bridge wire in place and yet not interfere with the action of the slider in making contact with the wire. The bridge wire is stretched tightly in the groove and secured to the disk by soldering to two small pins driven radially into the disk about one-half inch apart.

BALANCING MECHANISM.

The balancing of the bridge is secured by the rotation of a shaft, working through a bushing inserted through the cover of the box and the bridge-wire disk, the whole being coaxial with the periphery of the disk. The bushing is retained in place by a brass collar, which is

soldered to its upper end and secured to the cover of the box. This collar also assists in keeping in place the celluloid cover of the paper scale.

From the lower end of the shaft, passing through the cover of the box and the bridge-wire disk, extends an arm three-eighths inch wide, parallel to the face of the wooden disk supporting the bridge wire. Just beyond the periphery of the disk the arm bends upward at right angles and carries the bridge-wire contact spring, which consists of a piece of No. 32 B. and S. spring brass one-eighth inch wide, doubled back upon itself in such a manner as to bring the contact under the arm, thus protecting the contact from mechanical injury.

The shaft is held in position in the bushing by means of a collar which carries the scale pointer, and is secured by a set-screw. The collar thus furnishes means of adjusting both the shaft and the pointer. Through the center of the shaft of the balancing mechanism there operates a plunger for closing the battery circuit. This plunger is keyed in such a manner as to prevent rotation within the shaft, while at the same time moving freely in the line of its axis. To the upper end of the plunger is fastened a circular handle of hard rubber which serves both to operate the plunger and rotate the balancing mechanism. The lower end of the plunger is cut down for a short distance to a smaller diameter, which works through a corresponding hole in the lower part of the shaft. A weak coiled spring, just sufficient to raise the plunger when released, is placed between the shoulder of the plunger and the bottom of the shaft. To the lower end of the plunger a small disk of hard rubber is fastened by means of a countersunk screw. This retains the plunger in place and also serves to insulate it from the battery switch.

BATTERY SWITCH.

The battery switch consists of two platinum-tipped springs so mounted upon the partition running through the center of the box that when the plunger is depressed the upper spring is forced down against the lower one, thus closing the battery circuit. This switch has the advantage of a rubbing contact, since the plunger has a movement sufficiently great to depress the lower spring for a short distance, thus causing a rubbing movement between the two springs and insuring a perfect contact. The switch is also highly advantageous from the fact that it thoroughly protects the battery of the instrument, since the moment the hand is taken from the handle of the balancing mechanism the plunger is released and the circuit is opened. Thus the battery is used only during the actual observation, and consequently has a much longer life.

SCALE.

The soil hygrometer is provided with a direct reading scale, the readings of the instrument being expressed in terms of the percentage of some definite water content, taken as a standard. In order that this may be accomplished it is necessary at the time the instrument is

installed to adjust either the electrodes or the temperature cell so that the reading of the instrument may correspond with the water content of the soil at that time. The manner in which this is accomplished will be considered later. The direct reading scale is based upon the fact that within the limits between which moisture observations are usually made the electrical resistance of the soil is inversely proportional to the square of the water content, expressed in percentage of the dry weight of the soil.[1] This relation does not hold strictly for all soils as we approach the limits, but the agreement is so close that for ordinary observations it was not deemed necessary to provide the instrument with special scales for different soils.

If we take 100 on the scale to express some particular percentage of water, which should be chosen to agree as nearly as possible with the most favorable water content of the soil, then 75 expresses the condition of the soil when it contains but 75 per cent of the optimum water content, and 125 expresses the condition when it contains 125 per cent of the amount present in the optimum condition, and so on. The middle point of the bridge wire is chosen as the 75 point of the scale. If we assume the resistance at this water content to be 1,000 ohms, for convenience in computation, the corresponding resistance for any other point of the scale can be calculated from the following formula:

$$R_x = R_{75} \frac{75^2}{x^2}$$

in which x represents the point on the scale, the corresponding resistance of which we wish to determine, R_{75} represents the resistance chosen for the 75 point, in this case 1,000, and R_x represents the required resistance corresponding to the point x. For this formula the following calibration table has been prepared.

Hygrometer calibration table.

Scale x.	Resistance R_x.
140	287
135	309
130	333
125	360
120	391
115	425
110	465
105	510
100	563
95	623
90	694
80	879
85	779
80	879
75	1,000
70	1,148
65	1,331
60	1,563
55	1,860
50	2,250
45	2,778
40	3,516
35	4,592
30	6,252

[1] Bulletin No. 12, Division of Soils.

To calibrate the hygrometer a resistance of 1,000 ohms is inserted between the middle and left-hand binding posts. The resistances given in the table are then inserted successively between the middle and right-hand binding posts. When the bridge is balanced against any of these resistances the table gives the corresponding scale reading.

To avoid error, due to lack of uniformity in the bridge wire, the scale is calibrated for every 10, or better, for every 5 divisions. The bridge wire is chosen of such a length that the graduation extends through the whole available space on the scale, so as to make the scale as open as possible. The scale is protected by a sheet of transparent celluloid, the edges of which are held in place by a nickel-plated ring secured to the top of the box, as shown in the illustration.

TELEPHONE RECEIVER.

The telephone receiver used in balancing the bridge is of the watch-receiver form, with a hard-rubber case to minimize the danger of a stray circuit from the receiver to the earth. One terminal of the receiver is connected with the balancing mechanism by means of a spring brass friction contact between the bridge-wire disk and the outer bushing of the balancing mechanism. The other terminal is connected to the middle binding post of the instrument.

INDUCTION COIL.

In order to prevent polarization of the soil electrodes it is necessary to employ an alternating current for measuring purposes. This is secured by the use of a small induction coil, $2\frac{3}{4}$ inches in length, with a laminated core about one-half inch in diameter, built up of No. 15 B. and S. soft iron wire. The primary of the induction coil consists of four layers of No. 24 B. and S. D. C. C. copper wire and the secondary of three layers of No. 36 copper wire. This coil is placed in the bottom of the small case which holds the current interrupter, and is held in position by means of cork wedges placed at the ends. The terminals of the secondary coil are soldered to the side hinges. These hinges are in turn connected to the right and left hand binding posts. The hinges thus form very convenient flexible contacts, combining both compactness and durability.

CONDENSER.

Owing to the fact that a small but appreciable capacity may exist between the two electrodes buried in the soil, it has been necessary, in order to secure sharp readings, to place a small condenser parallel with that arm of the bridge adjacent to the soil resistance, which would throw the two capacities on opposite sides of the bridge with respect to the telephone receiver (see fig. 4). In this way the disturbing capacity in the soil can be entirely eliminated, and the minimum in the receiver becomes sharp and distinct. Since this capacity between the

electrodes in the soil varies with different moisture contents of the soil, and under certain other conditions which have not yet been fully determined, it is necessary that the condenser be capable of adjustment. A small condenser has accordingly been devised which is capable of continuous adjustment throughout the range of capacity necessary to balance the capacity effect between the electrodes in the soil. This condenser depends upon the principle that the electrostatic capacity of a series of insulated plates varies greatly with the distance between the plates, the capacity being inversely proportional to the square of this distance. Spring brass strips, 2 inches wide and 3 inches in length, are given a slight curvature, so that when the plates are stacked up between thin sheets of mica with the alternate plates projecting at opposite ends of the pile the plates and mica do not form one compact mass, but are separated to a greater or less degree, depending upon the curvature of the plates and their thickness. To the ends of the plates projecting from one end of the pile is soldered a common terminal, while a similar terminal is soldered to the plates at the other end. These two sets of plates are in this way thoroughly insulated from each other by means of the pieces of mica, while the distance between them can be greatly varied by simply compressing the pile. A small hard-rubber plate is placed upon the top of the condenser as thus built up, and the whole is placed in a frame which has a small compression screw, the end of which works in a corresponding depression in the center of the hard-rubber plate. Upon changing the position of this compression screw we compress or release the condenser, and so vary its capacity at will. The terminals of the condenser are connected by means of the hinges with the middle and right-hand binding posts.

CURRENT INTERRUPTER AND BATTERY.

The current interrupter consists of a small pocket buzzer giving about 120 interruptions per second. This buzzer is placed in a small case and packed with cotton wool, which serves to muffle all sound from the buzzer and thus facilitates the discernment of slight sounds in the receiver. This form of interrupter is of great convenience in such an instrument, as it is protected from injury and permits rough treatment without requiring readjustment. The case for the battery is of such dimensions as to allow any dry cell of standard size to be used. This enables one to secure without difficulty a dry cell adapted for use in the instrument when it becomes necessary to supply a new cell. The battery is held in its case by means of cork wedges, which permit it to be easily and quickly removed.

METHOD OF OPERATING THE SOIL HYGROMETER.

In using the soil hygrometer in the field it is customary to provide a small platform, consisting of a stake with a board nailed across its top, upon which to rest the instrument. The arrangement of the connections is illustrated in fig. 3. The wire leading from the temperature

cell is connected to the left-hand binding post of the instrument; the wire which is common to both cell and electrode is attached to the middle binding post, while the third wire is attached to the right-hand binding post. The ends of the wires should be scraped bright with a dull knife, in order to insure good electrical connections with the binding posts.

These connections being made, the telephone receiver is pressed tightly against the ear and the handle of the instrument pushed down, when a buzzing sound will be heard in the receiver. Holding the

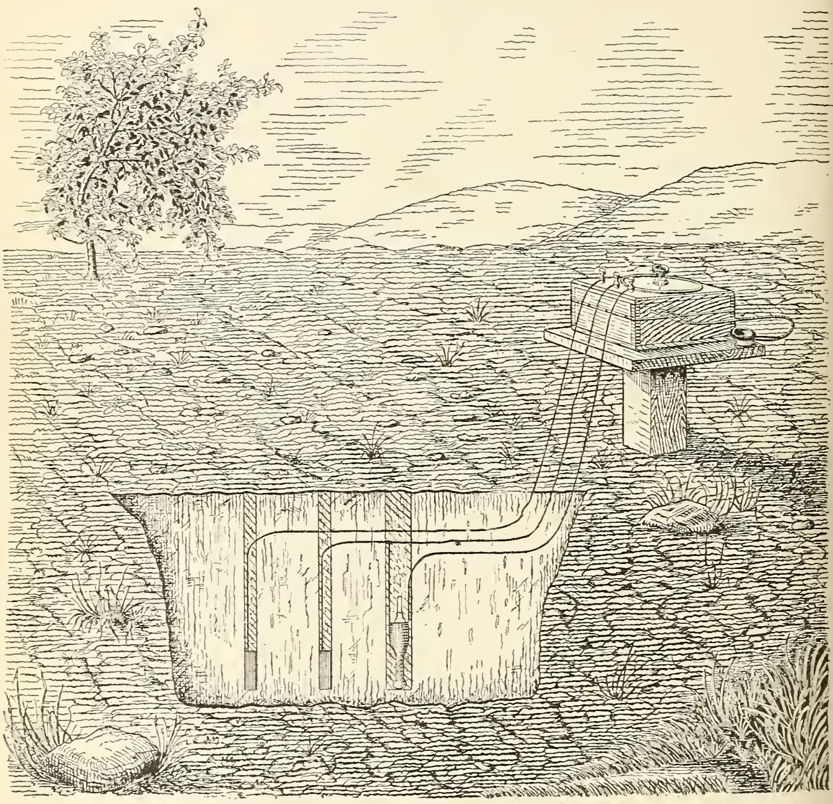

FIG. 3.—Sectional view of the soil, with electrodes and cell properly connected to the hygrometer.

handle down so as to keep the battery switch closed, the pointer is rotated to either right or left until the position is found at which the note in the telephone receiver is no longer heard. On rotating the pointer to either side of this position the sound in the receiver should gradually increase. In case difficulty is found in locating the exact position of balance, it will be found to be of assistance to rotate the pointer rapidly back and forth over the position of no sound, locating points of equal sound intensity on either side. The mean position

between these two points gives the position of balance, and the number opposite the pointer gives the desired reading.

In case it is not possible to obtain a well-defined minimum in the sound in the receiver, recourse should be had to an adjustment of the screw of the condenser inside the box. Upon compressing or releasing the condenser a position of the compression screw will be found at which the minimum in the receiver is much more distinct. In making the preliminary readings with the instrument it will usually be found more satisfactory to release the condenser as much as possible by loosening the compression screw. If a number of electrodes are to be read by the same instrument, it may be found necessary to adjust the condenser for the various electrodes. Usually, however, a common adjustment of the condenser can be found which will be satisfactory for all readings.

If the instrument is to be shipped, it is advisable to compress the condenser in order to prevent possible disarrangement of the condenser plates. It is also necessary in such cases to place a washer between the head of the plunger and the end of the shaft, or else disconnect one terminal of the battery, in order to prevent the closing of the battery circuit during transportation.

LOCATION OF FAULTS IN THE INSTRUMENT.

It may sometimes happen that during a journey or through careless handling an instrument may get out of adjustment or fail to work properly. Some of the faults which are likely to occur will consequently be discussed.

In case there is no sound in the telephone receiver when the battery switch is closed, the failure may be due to (1) a run-down battery; (2) lack of contact between the two springs of the battery switch, due to dirt on the platinum contacts; (3) improper adjustment of the current interrupter; (4) broken connections, either in the primary or secondary circuits of the induction coil; (5) failure of the contact spring of the balancing mechanism to make contact with the bridge wire; (6) broken receiver circuit.

The question as to whether the difficulty exists in the bridge connections or is due to the current interrupter can generally be decided by closing the battery switch and placing the ear close to the current-interrupter box, when, if the interrupter is working, a slight note will be heard. If the interrupter does not work, it should be first examined. This is done by taking the cover off from the small case containing the interrupter, which will be found packed in cotton. The current interrupter should be taken out and the metal cover removed. Keeping the battery switch closed, it should now be determined whether the interrupter can be made to work by some simple adjustment of the contact. If this can not be done, the connections with the battery and induction coil should be examined. If these connections are found to be perfect, it is probable that the battery is defective and should be replaced by a new one.

In case the current interrupter works satisfactorily and still no sound can be heard in the receiver, it is evident that a broken circuit exists. This can generally be found without difficulty by carefully examining the connections, which should be in accordance with the accompanying diagram (fig. 4).

If the difficulty appears to be in the bridge connections, the bridge-wire slider should be first examined, to see whether it makes contact

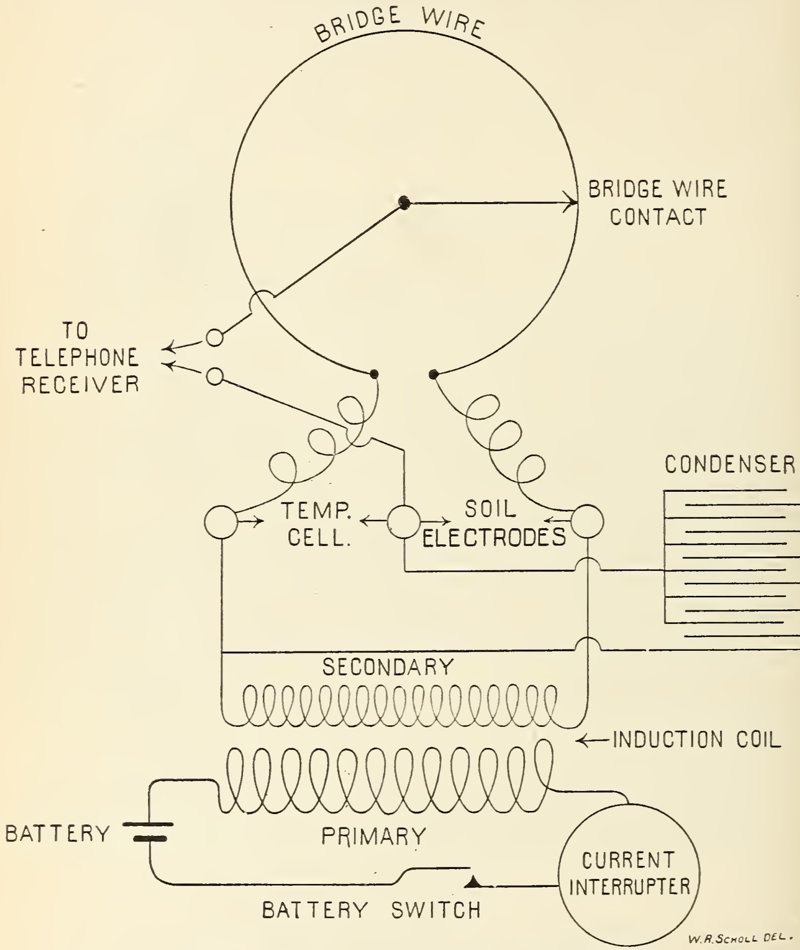

FIG. 4.—Diagram of interior connections of hygrometer.

with the bridge wire, and adjusted, if necessary, by carefully bending the contact spring up or down until the slider makes contact for all positions of the scale. This is the cause of the trouble when a note can be heard in the receiver for certain parts of the scale only. In case the bridge wire has become loosened, it should be unsoldered from one of the pins in the periphery of the disk, carefully placed in the groove in the disk, drawn taut, and resoldered.

In case the faults seem to be in the receiver circuit, the connections inside the box should be examined, as well as the screws binding the cord terminals to the telephone receiver. If necessary, the face of the receiver can be removed by unscrewing it and the inside connections examined.

A pair of test coils accompany each instrument. These coils are to be connected with the three binding posts in such a manner that the common terminal of the two is connected to the middle post and the single terminals to the right and left hand binding posts. When these two coils are connected to the instrument in the manner described, a balance of the bridge should be obtained at the 75 point of the scale. In case the balance can not be obtained at or near this point, the instrument is either out of adjustment or else broken connections or short-circuiting exists. If no balance of the bridge can be obtained by means of this coil, all of the connections should be carefully examined to see if they correspond with those given in the diagram (fig. 4). The trouble might also be due to a short-circuiting in the condenser, which would connect directly the middle and left-hand binding posts. In such cases the connection of the condenser with the middle hinge should be broken in order to see if this remedies the trouble.

If a balance is obtained at a position differing by two or three divisions from the 75-point mark, the instrument is out of adjustment. This can be remedied by loosening the screw in the pointer collar, and, holding the contact arm rigidly at the position of balance, bringing the pointer to coincide with the 75-point position, and then tightening the screw in the collar. In case it should be necessary to remove the shaft of the balancing mechanism for the purpose of repairing or renewing the platinum bridge-wire contact, this adjustment should always be made after the instrument is once more assembled.

The adjustment of the instrument should always be determined by the use of these test coils before beginning field work. A failure to secure a balance of the instrument when connected with the soil electrodes in the field, provided the instrument is already in adjustment, will be discussed later (p. 26).

SOIL ELECTRODES AND COMPENSATING TEMPERATURE CELL.

It has been mentioned above that the effect of varying temperature on the soil resistance is compensated by balancing this resistance against the resistance of an electrolytic cell containing a solution at the same temperature and having the same temperature coefficient as the soil. The resistance of different soils, however, varies so greatly that in order to bring the readings upon the most sensitive portion of the instrument scale it is necessary that the ratio of the soil resistance to that of the temperature cell be capable of adjustment. This can be accomplished by varying the resistance of the compensating cell or by changing the area of the soil electrodes. Both methods have been employed, but the former is more convenient and is the one generally recommended.

ADJUSTABLE TEMPERATURE CELL.

The adjustment of the instrument reading by changing the resistance of the temperature cell instead of changing the area of the soil electrodes has the important advantage of obviating the necessity of disturbing the electrodes. This also permits the use of carbon instead of metal electrodes, the former seeming to possess some advantages over over the latter.

The adjustable temperature cell is illustrated in fig. 5, which shows a longitudinal section. It is constructed of brass and hard rubber, and is made in two parts, one of which is capable of adjustment within the other. The cell is used in a vertical position, the cylindrical bulb being at the top. The lower part of the outer portion consists of a piece of hard-rubber tubing, 3 inches long and five-sixteenths inch inside diameter, with walls one-sixteenth inch thick. Into the lower end an unburnished, nickel-plated, brass plug is sealed, which forms one electrode. The brass cylinder, nickel-plated on the inside, constitutes the other electrode. Suitable insulated connecting wires are soldered to the two electrodes and secured to the sides of the cell with wax. The outer surfaces of both electrodes are insulated by thoroughly covering them with insulating wax or paint. The adjustable plunger consists of a hard-rubber rod, 5 inches long and one-fourth inch in diameter, which works through a short piece of closely fitting flexible rubber tubing attached to the tubulure on the end of the brass cylinder.

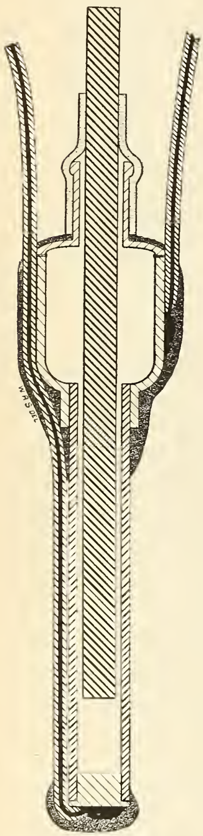

FIG. 5.—Longitudinal section of adjustable temperature compensating cell.

The cell is filled to a point one-fourth inch above the upper end of the hard-rubber tubes with a salt solution which has the same electrical temperature coefficient as the soil. The solution consists of nine parts of a solution of four-fifths normal sodium chloride and one part of 95 per cent alcohol. The determination of the resistance-temperature coefficient of soils, which gave the data for the preparation of this solution used in the temperature cell, has been described in Bulletin No. 7 of this division.

When the plunger of the adjustable cell is pushed down into the solution, a portion of the solution is displaced and the resistance of the cell is increased. By thus varying the position of this plunger we are enabled to increase continuously the resistance to about three times the resistance of the cell when the inner tube is drawn down entirely out of the lower portion of the cell. In adjusting the reading of the instrument the plunger is moved up or down until the desired reading is obtained. This form of compensating cell has sufficient

range to permit adjustment in all cases except when the electrodes are much too large or too small. In such cases it is necessary to increase or diminish the size of the electrodes and then make the final adjustment by means of the cell as above.

CARBON ELECTRODES.

Carbon forms a more satisfactory electrode than metal, since it seems to give a more perfect contact with the soil grains, due undoubtedly to the fact that the moisture permeates to some extent the carbon itself.

A form of electrode which has been used extensively in connection with shallow depths consists of a rectangular strip of carbon 3 inches long, five eighths of an inch wide, and three-sixteenths of an inch thick. A series of diagonal cuts (see fig. 6) are made in the edge of the carbon, just wide enough to allow the connecting wire to be forced into place, the contact being afterwards covered with insulating wax. A more substantial contact is made by boring a hole through the carbon strip near one end, in which is inserted an unlacquered, round-headed, brass machine screw, provided with a nut. A $\frac{3}{8}$-inch 8–32 machine screw is suitable for this purpose, the hole being of such a size as to make a snug fit with the screw, which is drawn tight by means of the nut. The connecting wire is then soldered with rosin in the slot of the screw-head and all exposed metal covered with insulating paint.

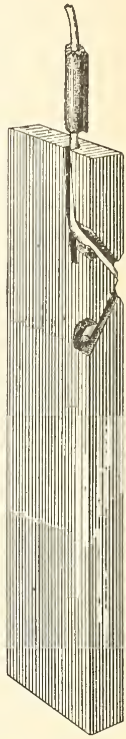

Fig. 6.—Rectangular carbon electrode, showing saw-cut contact with wire.

A form of electrode which is well adapted to both deep and shallow work is illustrated in fig. 7, together with a longitudinal section, showing the manner in which contact with the wire is made. The electrode is one-half of an inch in diameter and $2\frac{1}{2}$ inches long, the general form being that of a paraboloid of revolution. This form is given so that when the electrode is forced into a conical hole in the soil perfect contact will be made at every part of the electrode. A cylindrical cavity with corrugated sides is made in the upper end of the electrode, into which the end of the connecting wire is inserted, and which is then nearly filled with fusible metal which holds the connecting wire firmly in place and makes perfect contact

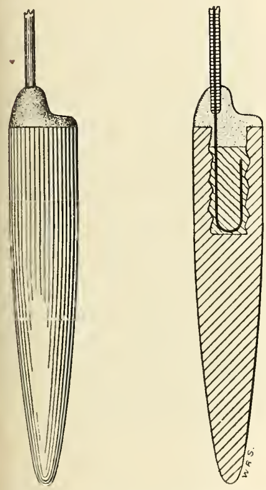

Fig. 7.—Carbon electrode, with longitudinal section to show construction.

with the carbon. The upper end of the electrode and any exposed portion of the conducting wire are covered with insulating wax.

A modification of the electrode just described can be constructed in the laboratory from unplated dense electric-light carbons (preferably those made for inclosed arc lamps). These carbons, which are one-half of an inch in diameter, are sawed into 3-inch lengths and ground to a conical point on a stone. A three-sixteenths-inch hole is then drilled in the other end to the depth of half an inch, which is afterwards corrugated by means of a suitable turning tool. The end of the insulated wire, which has been scraped bright and clean, is bent into a loop and inserted in the corrugated cavity, around which is run a fusible metal. Wood's fusible metal, consisting of 1 to 2 parts of cadmium, 2 parts of tin, 4 parts of lead, and 7 to 8 parts of bismuth, which melts at 66° to 70° C., has been found suitable. It is advisable to heat the carbon about the cavity with a Bunsen flame before running in the metal, so that the latter will not be cooled by coming into contact with the carbon. The metal and wire should finally be thoroughly covered with insulating wax as before.

ADJUSTABLE METAL ELECTRODE.

When the adjustment is made by changing the area of the electrode, it is most convenient to use metal electrodes of nickel-plated copper wire of about No. 24 B. and S. gauge. Two of these wires, 4 or 5 feet in length, are attached at one end to two insulated connecting wires by means of the telegraph splice (see p. 25), the conducting wires being of sufficient length to reach from the point where the electrodes are to be buried to where the instrument is located. The splice is now thoroughly insulated with wax and tape (see p. 25), and the wires are buried at the desired depth, parallel to each other and from 1 to 2 feet apart, by excavating two very narrow ditches in the soil, after which the soil is thoroughly tamped back into place. When the ground about the electrode has become thoroughly settled, which generally requires two or three days, a small excavation is made in the soil at the free end of the wire, and small portions of the electrode are cut off until the desired reading is obtained. It is, of course, necessary to have the electrode entirely covered at the time the observation is made. This method of adjustment is not as convenient as that of the adjustable temperature cell, and is open to the rather serious objection that the electrodes are not in a normal condition and are liable to undergo slight subsequent changes.

If the investigation of the water content of a certain layer of the soil is desired, the wire is bent into a zigzag form of such dimensions as to traverse the depth of the layer under investigation. When this form of electrode is desired it is not necessary to use the adjustable temperature cell, and it has been customary to use a form which is hermetically sealed, although the adjustable cell is equally well adapted to this use, and possesses the advantage that the final adjustment can be made by the cell instead of by means of the electrodes.

INSTALLING THE ELECTRODES AND TEMPERATURE CELL.

In the form of moisture instrument previously used by this division a shelter box was placed near the plats of ground on which moisture investigations were being made, and the various electrodes and temperature cells were connected by underground lead-covered cables with these shelter boxes in which the moisture instruments were kept. The terminals of the various electrodes and temperature cells were brought up to a suitable switch board, which enabled connections to be quickly made with the moisture instrument. This arrangement is somewhat expensive, however, especially in case the different plats under investigation are some distance apart. It is therefore recommended that the three wires leading from the electrodes and the temperature cell be brought to the surface a short distance from the electrodes, and that the soil hygrometer be carried from point to point, and connected with these wires at the time of taking the observations.

In installing the electrodes for moisture observations it is of course important that a typical portion of land be selected, special precaution being taken to select ground which is not depressed at that point, as any depression would tend to permit an excessive accumulation of water, and thus render the moisture observations inaccurate when applied to the conditions over the whole plot.

It is also important that the electrodes should be located in such a position as not to be disturbed by cultivation. If the electrodes are less than 6 inches deep, the treading of a man or a horse on the ground immediately above the electrodes might so alter the compactness of the soil and its relation to water as to change materially the readings of the instrument. In such cases, therefore, both the electrodes and temperature cell must be so placed as to be out of reach of the cultivator and the horse, and care must be taken not to tread on the earth immediately above the electrodes when taking the observations. At lower depths such precaution is not necessary. For most field crops in Eastern soils the water content at a depth of 5 to 8 inches seems to give the most important information regarding the moisture content of the soil. The depths at which moisture observations should be carried must necessarily vary to some extent with different soils and under different conditions, and the particular depths at which the electrodes should be placed will suggest themselves to the investigator.

DEEP ELECTRODES.

In installing the electrodes at the lower depths an inch auger hole is made in the soil down to the upper limit of the depth at which electrodes are to be placed. A stick, the end of which is in the form of a cone, three-eighths inch in diameter and 2 inches long, is then forced down until the base of the cone is even with the bottom of the original auger hole. The electrode is then carefully lowered by means of its connecting wires into this cavity prepared for it, and pushed firmly

into place with the other end of the stick. The hole is then filled with moist soil, care being taken to thoroughly tamp the soil with the rod during the process of refilling. The other electrode is buried in a similar way at a distance of 2 or 3 feet from the first. The resistance between the electrodes is practically confined to volumes of soil not exceeding 6 inches in diameter, with the electrodes as centers, so that there is no special advantage in separating them further, unless it is to avoid the effect of a possible lack of uniformity in the soil.

SHALLOW ELECTRODES.

In case the electrodes are not to be located deeper than the land was plowed the hole can generally be made by the stick alone. The electrode is then forced into place by means of the stick, and the hole filled with earth and thoroughly tamped as before.

INSTALLING CELL.

The adjustable temperature cell is filled with the salt solution (see p. 20) and buried in the soil somewhat to one side of a line joining the two soil electrodes and at a depth such that the lower part of the cell occupies the same layer of soil as the electrodes. This is conveniently done by boring a hole similar to that made for the electrodes in which the cell is placed, any vacant space being carefully filled with soil. To adjust the cell a small excavation is made above the cell to expose the plunger. In case the cell is located so deep that such an excavation is not practicable the plunger may be spliced to a stiff wire (No. 10 iron wire is satisfactory) which is cemented in the hole in the end of the plunger by means of the insulating wax. The wax should be allowed to become thoroughly hardened before attempting the adjustment.

CONNECTION OF ELECTRODES AND CELL TO SOIL HYGROMETER.

The wire leading from the upper electrode of the temperature cell is spliced (see p. 25) to the wire leading from one of the soil electrodes, the common terminal, which is joined to the middle binding post of the soil hygrometer, being known as the combination wire. The other wire from the cell is known as the cell wire, and is joined to the left-hand binding post, while the wire from the other carbon is connected with the right-hand binding post. (See fig. 4.)

WIRE.

The wires used for connection should in all cases be provided with that grade of insulation known to the trade as "waterproof," either when used in the soil or when exposed to the weather. Where wires are protected from rain or excessive dampness a cheaper grade of insulation may be used. In making long connections a three-conductor lead-covered cable, which can be safely buried under ground, is convenient and not expensive. The three conductors of this cable should be provided with insulation of different colors to facilitate connections.

SPLICING AND INSULATING WIRES.

Care must be exercised in splicing wires. The best form of connection for field use is the telegraph splice, illustrated in fig. 8, *a*. In making this connection the insulation should be removed from each wire for a distance of at least 3 inches from the end and the wire scraped bright and clean. The wires are then brought together, their ends pointing in opposite directions and twisted together at a point about three-fourths of an inch from where the insulation begins. This forms the middle part of the splice. Grasping this firmly in a pair of pliers, the free end of each wire is wrapped tightly around the straight portion of the other, as shown. This splice should be used in all cases where it is necessary to lengthen wires. In temperature work these wires should be soldered if possible after being spliced.

The method of joining one wire to the middle of another, as when

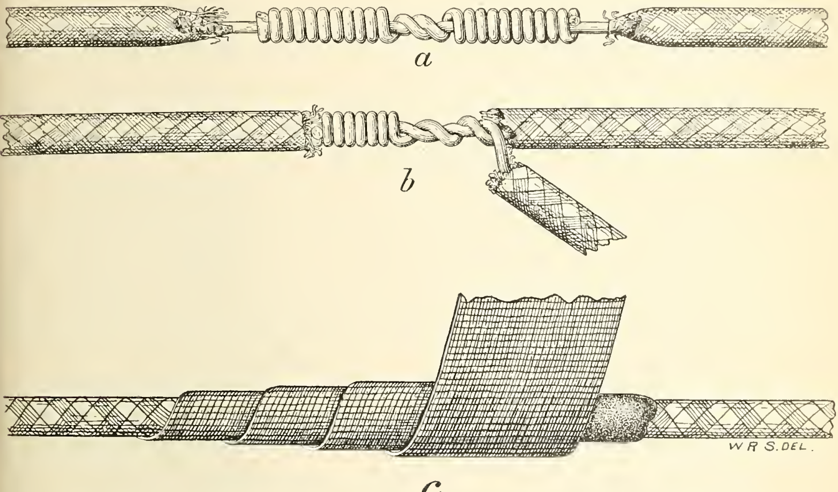

FIG. 8.—Splicing and insulating wires: (*a*) Telegraph splice; (*b*) Side connection; (*c*) Taping the splice.

making connection between the temperature cell and the soil electrode, is illustrated in fig. 8, *b*. The insulation is removed for a distance of 1½ inches from the wire to which the splice is to be made. The end of the other wire is prepared as before. The wires are now tightly twisted together close to the insulation for about half an inch, and then the end of the free wire is wrapped helically about the other, as shown.

All splices should be thoroughly insulated, both to prevent the contact from being impaired through subsequent exposure and to prevent the occurrence of stray circuits. The exposed portions should be first covered with insulating wax, which is applied when hot. The preparation known as "Chatterton's Compound" has been found very satisfactory. A thin coating of this will suffice, but care should be taken to see that all parts are covered. It is then advisable to wrap the connection with insulating adhesive tape, which is wound spirally about the splice, as shown in fig. 8, *c*.

ADJUSTING THE READINGS OF THE HYGROMETER BY MEANS OF THE TEMPERATURE CELL.

After the soil about the electrode has been allowed to settle, which usually requires two or three days, and preferably after a heavy rain, the wires leading from the electrodes and the temperature cell are connected with the instrument in the manner described (see p. 24), and a reading of the instrument is taken by pushing down the plunger in the handle until a note is heard in the telephone receiver, and then rotating the handle until a point is found at which the note vanishes. The inner rod of the temperature cell is then raised or lowered until the desired reading on the instrument is obtained.

By pushing the inner rod into the temperature cell the reading on the instrument becomes higher; conversely, by raising the inner rod the instrument gives a lower grading. In case it is not possible to secure the balance on the instrument—that is, a point where there is no sound in the receiver for any position of the inner rod of the adjustable temperature cell—it becomes necessary either to increase or diminish the area of the soil electrodes. If the sound seems to be weaker when the inner rod of the compensating cell is pushed entirely down, and the pointer is at the lower number, then the soil electrodes are too small and must be made larger. If, on the contrary, the sound in the receiver diminishes in volume when the pointer approaches the higher numbers and the inner rod in the temperature cell stands in its highest position, then the electrodes are too large and must be cut down. In case no difference can be perceived in either of the positions, it will be necessary to change the size of the electrodes and observe the effect.

In all cases it is desirable to adjust the instrument so that 100 on the scale represents as nearly as possible the optimum condition as regards water content. When the instrument is used in this manner the instrument readings represent the percentage of the optimum water content in the soil. The scale is consequently much superior to purely arbitrary units, since it gives a definite idea of the amount of water present.

In case it is desired to determine the percentage of water in the soil, a number of samples for moisture determination should be carefully taken at the depth of the electrodes at a time when the soil is in its most favorable condition, i. e., when the reading of the instrument is near 100. At the same time a careful reading of the instrument should be taken. The value of the 100 point of the scale in actual percentage of water can be determined from the following equation:

$$P_{100} = P_x \frac{100}{x}$$

in which P_x is the actual percentage of the water as found from the samples, which correspond to the reading x on the instrument at the time the samples were taken, while P_{100} is the required percentage of the water corresponding to the 100 point on the scale.

To take a concrete case: Suppose that the value of P_x as found from sampling and drying was 18.6 per cent, while the reading x of the instrument was 95, we then have

$$P_{100} = 18.6\,\frac{100}{95} = 19.6 \text{ per cent},$$

or the water content corresponding to the 100 point on the scale is 19.6 per cent.

Having determined the water content for the 100 point, the water content corresponding to any other reading can at once be found by multiplying the water content at 100 by the scale reading expressed as a percentage. To illustrate again: The water content when the instrument reads 80 in the above example would be $19.6 \times .80 = 15.7$ per cent; when the reading was 125, it would be $19.6 \times 1.25 = 23.5$ per cent, and so on.

As has been mentioned before, the inverse square law upon which the moisture scale was constructed is not strictly applicable to all soils, and when especially accurate results are desired, the departure from this law for the soil in question should be determined by comparing the instrument readings with careful moisture determinations, from which the correction to be applied to the instrument readings can be obtained. For example, suppose from sampling and drying, the water content when the instrument reads 80 was found to be 16.7 per cent instead of 15.7 per cent, as above, then, since the instrument reading was 1 per cent too low, at 90 it would be 0.5 per cent too low, at 95, 0.25 per cent too low, and so on. A similar determination should be made above the 100-point position to determine the departure on that side.

ELECTRICAL METHOD OF DETERMINING TEMPERATURE.

The change in the electrical resistance of metals with temperature enables us to employ this property as a thermometer by measuring variations in the electrical resistance of a suitable coil of wire located at the desired point. This method has the very important advantage of enabling the temperatures in very inaccessible places to be determined, owing to the fact that it is only necessary to have a small temperature coil at the point where it is desired to make the measurements, while the measuring instrument can be located at any convenient place, connection with the temperature coil being made by means of wires. A convenient instrument for this purpose has been devised and lends itself readily to the measurement of temperatures in inaccessible places, such as the temperature of the soil at various depths, the temperature of fermenting tobacco heaps, of rooms, of tanks, and, in fact, at any point where it is desired to determine the temperature and where it is inconvenient to use mercurial thermometers.

ELECTRICAL THERMOMETER.

This instrument is of the same dimensions and general construction as the soil hygrometer, the essential difference between the two instru-

ments being that in the soil hygrometer two arms of the bridge—namely, the soil resistance and the temperature cell—are outside the instrument, while in the electrical thermometer it is necessary to have only one arm of the bridge—namely, the temperature coil—outside the instrument. In other words, the compensating cell in the soil hygrometer has been supplanted in the electrical thermometer by the comparison coil within the instrument. The condenser is omitted, since the slight capacity of the temperature and comparison coils are practically equal and no disturbing effect is noticed. The comparison coil is made of manganin wire, the resistance-temperature coefficient of which is practically zero at ordinary temperatures.

Different metals vary in the change in electrical resistance which they experience with the change in temperature. In order to make the thermometer sensitive it is important to use a metal having a high temperature coefficient. For this purpose iron has been selected, as it has the greatest temperature coefficient of any of the common metals and also possesses the advantage of a relatively high specific resistance, thus necessitating the use of only a small quantity of wire and enabling temperature changes to be taken up more quickly. The wire in the temperature coil is of No. 36 B. and S. gauge, drawn from iron as free from carbon as possible, and is covered with single cotton insulation. Since the temperature coefficient of iron seems to vary greatly with the amount of carbon present, it was deemed necessary to determine the temperature coefficient. This was done by making an open coil of a suitable length of the wire, providing it with heavy copper lead-wires, and placing the whole in an oil bath which was gradually heated up to 160° F. and then allowed to cool slowly, the resistance of the wire being noted at 5 degree intervals as the bath cooled. The variation in resistance with the temperature, computed from the curves actually obtained, is given in the following table and is shown graphically in the accompanying curve:

Calibration table for electrical thermometer.

Temperature (degrees F.).	Resistance (ohms).
0	77.8
10	80.6
20	83.3
30	86.0
40	88.7
50	91.5
60	94.3
70	97.1
80	100.0
90	102.9
100	105.9
110	108.9
120	112.0
130	115.2
140	118.4
150	121.5
160	124.7

The resistance-temperature curve of the iron wire used in the temperature coils having been determined, the resistance of the temperature coil for every 10 degrees throughout the desired range can be found from the curve. The temperature instrument can then be calibrated by balancing the instrument against the resistances corresponding to these temperatures. The usual range of temperature for each instrument is 100 degrees on the Fahrenheit scale, which may be selected from any part of the absolute temperature scale up to temperatures which would destroy the temperature coil. This can be accomplished by adjusting either the resistance of the comparison coil or the temperature coils. The former method is preferable, since the temperature coils can then be used in connection with any instrument.

Owing to the fact that the variations in the resistance in the temperature coil are slight, as compared with the variations in the resistance between the soil electrodes, it is necessary to increase considerably the length of the bridge wire of the electrical thermometer in order to secure an open scale on the instrument. This is accomplished by adding to the bridge wire small coils of insulated platinoid wire. The sensibility, and consequently the range of the instrument, can be varied by changing the resistance of these coils. Any change, however, either in the resistance of these bridge-wire coils or of the temperature coil necessitates, of course, the construction of a new scale.

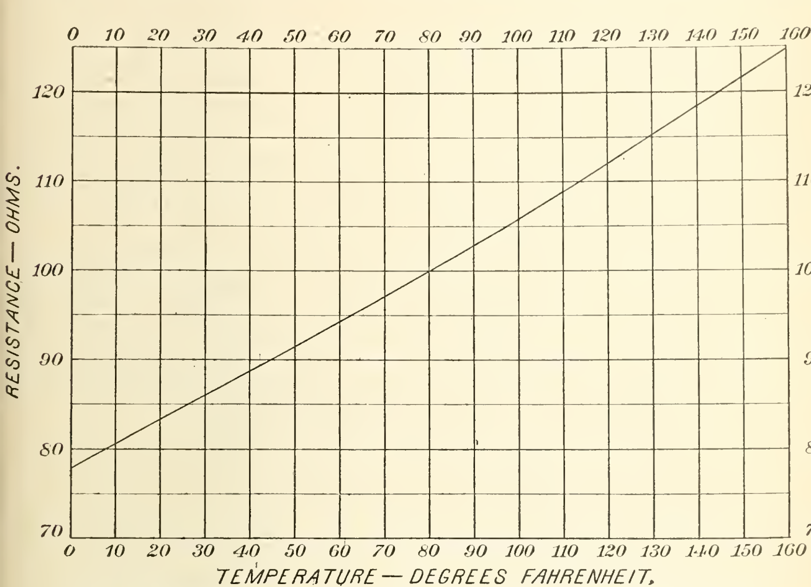

FIG. 9.—Resistance-temperature curve for the iron wire used in the temperature coils.

TEMPERATURE COILS.

The temperature coils are all adjusted to have a resistance of 100 ohms at 80° F. The coils are prepared by taking a suitable length of

wire (about 40 feet), doubling it to diminish induction effects, and then forming it into a narrow and rather loose coil about 8 inches in length. The coil is then adjusted to the required resistance and slipped into a piece of lead tubing about three-eighths of an inch in diameter, which is sealed at one end. The terminals of the coil are next soldered to the two wires of a two-conductor lead-covered cable, and the lead tubing which surrounds the coil is soldered to the lead covering of this cable. The coil is now thoroughly protected from moisture with the exception of a possible leakage through the lead-covered cable, which is prevented by immersing the free end in boiling paraffine until the air has been displaced. As an additional precaution it has been customary before putting the coil into its leaden sheath to saturate it with insulating oil.

The two-conductor cable to which the temperature coil is attached should be about 8 inches long. The insulated conductors project 4 inches beyond the end of the lead sheath, and to these terminals insulated wires of sufficient length to connect to the measuring instrument are carefully spliced (see p. 25). The spliced portions are then thoroughly covered with insulating wax and thoroughly taped, as it is very important that there should be no leakage at these points. When possible the spliced portions should be soldered.

When the connecting wires are each not more than 20 feet in length, No. 16 B. and S. copper wire may be used. If not more than 100 feet in length, No. 12 B. and S. wire gauge will be suitable for the connection. The error introduced by the resistance of the connecting wires of the dimensions given above will always be less than 1° F. More accurate results can be obtained by using larger wires.

USE OF THE ELECTRICAL THERMOMETER.

The electrical thermometer is operated in exactly the same way as the soil hygrometer. The terminals of the temperature coils are connected to the two binding posts of the instrument. The handle of the instrument is then depressed, when a buzzing note will be heard in the telephone receiver, which must be held close to the ear. Pressing the handle down firmly it is rotated to the right or left until the point is reached at which the sound in the receiver disappears or grows very faint. A little difficulty may be experienced at first in locating the exact position of the pointer for this minimum sound. It is of assistance in such a case to move the pointer rapidly back and forth over the point at which the sound disappears, noting the point at which the sound begins to increase on either side. The mean position between these two points gives the desired reading.

LOCATION OF FAULTS.

Owing to the similarity in construction of the hygrometer and the thermometer the directions given for the location and correction of

faults in the former instrument will apply equally well to the latter. The thermometer differs from the hygrometer only in the addition of a comparison coil, the connections for which are seen in the accompanying diagrammatic sketch of the instrument (fig. 10).

ADJUSTMENT OF INSTRUMENT.

The adjustment of the thermometer is easily tested by comparing some temperature, as determined by the temperature coil, with that

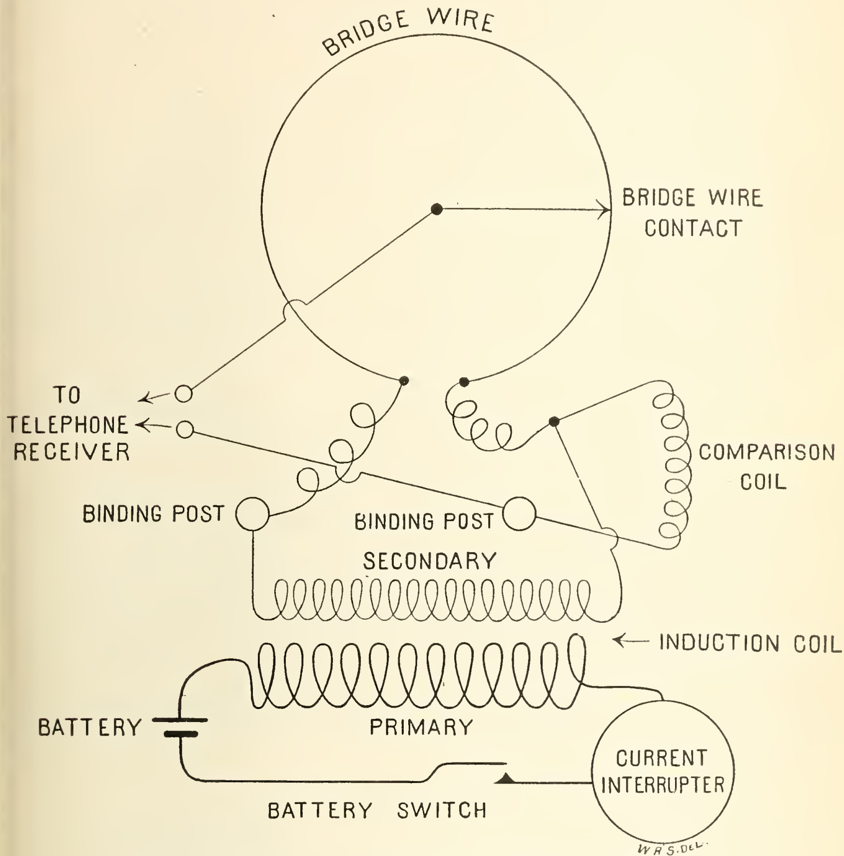

FIG. 10.—Diagram of interior connections of electrical thermometer.

given by a good mercury thermometer. Place a temperature coil in a large bucket of water at about room temperature, allow it to remain for several minutes to acquire the temperature of the water, and then, keeping it immersed, connect with the instrument and determine the temperature. At the same time the temperature of the water, which must be frequently stirred, should be determined by means of a reliable mercury thermometer. Should a discrepancy of more than one degree occur between the two determinations the test should be

repeated. It is also advisable to use several different temperature coils, as the difference might be due to an error in the adjustment of the temperature coil itself. If a practically constant discrepancy should be found between the readings of the mercury thermometer and the temperature as determined by the temperature coils, then the adjustment of the instrument is incorrect and the set screw holding the pointer should be loosened and the pointer adjusted until the readings of the instrument and the mercury thermometer agree. In case it is necessary for any reason to remove the shaft and the contact arm of the balancing mechanism, this adjustment should always be made on reassembling the instrument.

STANDARDIZATION OF TEMPERATURE COILS.

Although it is the intention to test each temperature coil carefully before it leaves the laboratory, it sometimes happens that the coils subsequently develop faults or are found not to be perfectly adjusted. It is therefore recommended that the various coils be compared with a good thermometer and with each other in the manner just described. In this way the corrections to be applied to the reading of each coil may be determined, and may or may not be used, according to the degree of accuracy desired.

APPARATUS FOR DETERMINING THE SALT CONTENT OF SOILS.

ELECTROLYTIC BRIDGE.

By slightly modifying the electrical thermometer the instrument can be adapted to the determination of the salt content of soils.[1] In fact, the instrument as used for this purpose is nothing more or less than a slide-wire bridge adapted to the measurement of electrolytic resistances. It is also equally applicable to the measurement of nonelectrolytic resistances. The instrument differs from the electrical thermometer only in having the resistance of the comparison coil in the third arm adjustable, in order to adapt the instrument to a greater range of measurements.

ROTARY SWITCH.

The adjustment of the comparison coil is accomplished through the agency of a small rotary switch operated from the outside of the box, by means of which 10, 100, or 1,000 ohms can be introduced as the third arm of the bridge. This is accomplished by joining in series a 10, 90, and 900 ohm coil connected to the three segments of the switch in such a way that the 10-ohm coil can be thrown in alone, or the 10-ohm and 90-ohm coils in series, or all three coils in series. The manner of

[1] For an account of this method see article by Thos. H. Means on "A Rapid Method for the Determination of the amount of Soluble Mineral Matter in a Soil," Am. Jour. of Science, Vol. 7, 1899, p. 264.

connecting the coils, together with the general connection of the instrument, is shown diagramatically in fig. 11.

The segments of the rotary switch are mounted upon hard rubber and the spring through which contact is made with the several segments is insulated from the shaft by which it is operated, in order to avoid stray circuits from the binding posts to the switch when using the instrument in the field.

All contact surfaces are heavily nickeled, in order to prevent oxida-

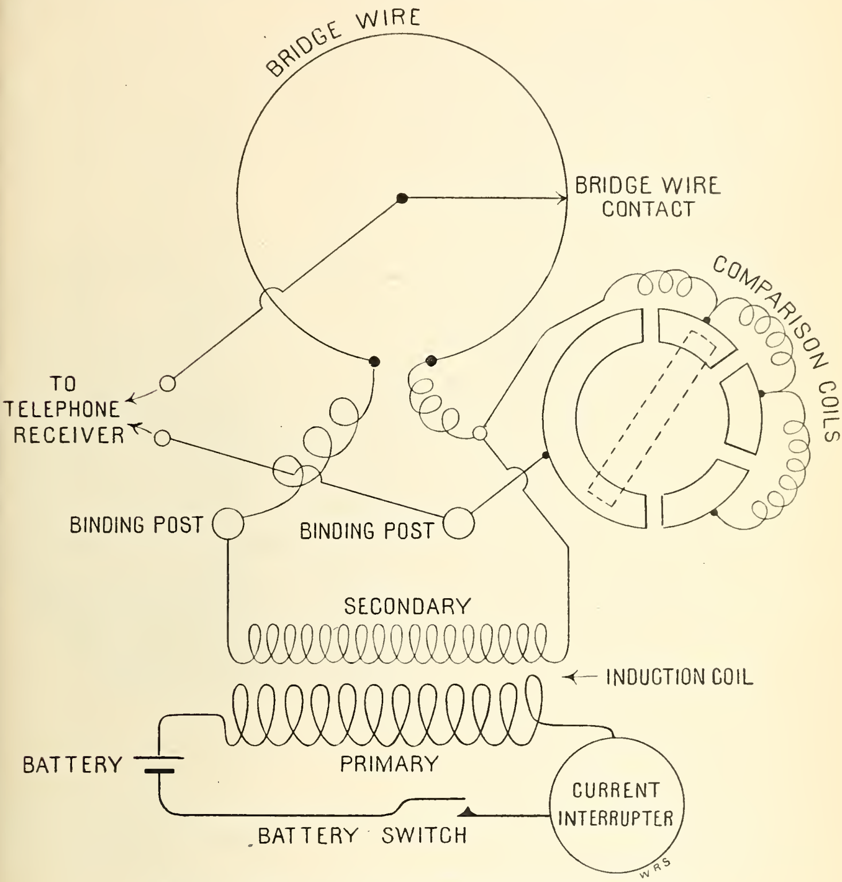

FIG. 11.—Diagram of interior connections of electrolytic bridge.

tion. The shaft operating the switch carries, just below the handle, a beveled collar upon which are three graduations, numbered 10, 100, and 1,000. These various resistances can be successively thrown in as the third arm of the bridge by simply bringing the corresponding graduation to coincide with an index mark upon the bushing beneath. By thus having the graduations upon the movable collar instead of upon a stationary scale, the index mark can be chosen in the position most

convenient for reading, so that the resistance of the comparison coil can be determined at a glance.

USE OF THE ELECTROLYTIC BRIDGE.

The instrument is operated in a manner similar to the hygrometer and thermometer. The resistance to be measured is connected with the two binding posts of the instrument. The handle is then pushed down and rotated until a point is found at which the sound in the

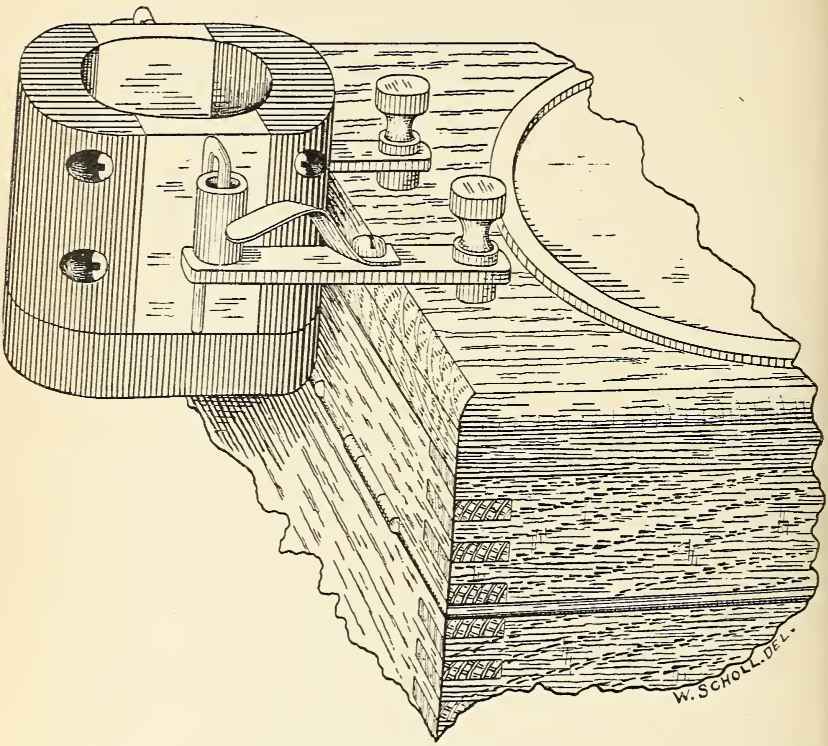

FIG. 12.—Electrolytic cell and mercury cups.

receiver disappears. In case a balance is not obtained with the 1,000-ohm coil thrown in, the other coils should be tried. It is always best to choose the coil which will bring the balance as near as possible to the center of the scale, as this is the most sensitive position.

The balance obtained, the resistance is found by multiplying the resistance of the comparison coil, as shown by the rotary switch, by the number on the scale opposite the pointer. Thus, if the comparison coil is 100 ohms and the reading on the scale is 0.92, the resistance between the posts is 92 ohms; if the comparison coil is 1,000 ohms and the reading on the scale is 8.5, the resistance would be 8,500 ohms, and so on. As the scale is graduated from 0.4 to 10, the instrument has a range of from 4 ohms to 10,000 ohms.

ELECTROLYTIC CELL.

The salt determinations are made in an electrolytic cell having a capacity of about 50 c. c. The cell and the mercury cups by which it is connected to the instrument are illustrated in fig. 12. The cell is constructed of hard rubber, with brass electrodes, which are heavily nickel plated but not burnished, in order to give greater surface area to the electrodes and to afford better contact with the moist soil. It is cylindrical inside with a cup-shaped depression in the base, this form greatly facilitating the removal of soil.

The mercury cups are so arranged as to be capable of being swung over the instrument during transportation, rendering the arrangement more compact. The mercury is retained in the cups when the instrument is being carried about by means of two flat springs fitting over the tops of the cups.

LOCATION OF FAULTS.

The methods of locating any faults which may occur in the instrument are similar to those used in the hygrometer and thermometer. For purposes of standardization and adjustment a 100-ohm coil will be furnished with each instrument. When connected between the two binding posts the bridge reading should of course be 1.0, if balanced against the 100-ohm coil. This test of the instrument should occasionally be made to note the adjustment. In case readjustment should be necessary, the screw holding the pointer is loosened and the pointer adjusted in the manner already described for the hygrometer.